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Teamwork on the Road: Efficient Collaboration in VANETs with Context-based Grouping

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Abstract

There is an emerging trend nowadays for vehicles to be equipped with an embedded on-board computing unit with communication capabilities to enhance the overall driving experience. Such a system enables vehicle-to-vehicle and vehicle-to-infrastructure communication and provides vehicles with up-to-date route and traffic information. However, as this information is not relevant for all vehicles, context-aware communication is considered to be vital for more intelligent inter-vehicular communication. Traditional network addressing schemes are not well suited because they do not take into account contextual properties such as location, direction, speed, time and information interest for group-based communication in large scale vehicular networks. The conventional network paradigms of multicasting and broadcasting to define groups cause too much overhead. First, there is no way to optimize network traffic based on the contextual characteristics of the nodes. Second, they do not take into account the mobility patterns of the vehicles and the road layouts. We propose a context-based grouping mechanism in which only relevant information is shared among the vehicles in a group. We evaluate our approach by formulating groups based on common spatial-temporal characteristics and shared interests. The simulated experiments show that by inducing our context-based grouping mechanism we can significantly reduce the irrelevant/redundant information flows and the overall network traffic usage.

Keywords: VANET, Context-aware, Information dissemination, Optimization, Grouping

1. Introduction

Telematic application development has recently been gaining a lot of attention from the research community [1, 2, 3, 4, 5]. Application areas include emergency response team notification, congestion monitoring and parking space allocation. In such environments the vehicles communicate with well-known centralized entities. However, in certain situations such as collision avoidance the vehicles may need to be able to communicate with each other without relying on a centralized communication infrastructure.

Optimizing information sharing with ad hoc communication between nodes in large scale vehicular networks is not straightforward. For example, vehicles that are moving on a highway can be interested in information on traffic

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jams ahead of them. This information may not be relevant for vehicles driving in the opposite direction. Processing the information to check for its relevancy and routing it to the right destination in a timely fashion is a challenge. The classical network paradigms of multicasting and broadcasting to define groups are too limited. First, there is no way to optimize network traffic based on the contextual characteristics of the nodes. Second, these classical paradigms do not take into account the mobility patterns of vehicles and the road layouts.

In this paper we address these issues by proposing a context-based grouping mechanism to optimize information dissemination using relevance backpropagation, a feedback-based algorithm for identifying and sharing useful information within a network of mobile nodes. Further information about our relevance backpropagation can be found in [6, 7, 8]. Our context-based grouping mechanism forms groups of vehicles using common contextual characteristics such as location, direction, speed, time and interest. Each group is represented by vehicles with special responsibilities regarding inter-group and intra-group communication. Our mechanism optimizes overall network communication by reducing redundant and irrelevant information. It also reduces the overall information processing overhead. For example, a representative vehicle can prevent the propagation of a message in its group if it knows that the vehicles inside the group are not interested in that message. Convoy driving [9], where a group of vehicles on a highway share a common destination, is an application that could benefit from our context-based grouping mechanism. Vehicles can form a convoy and elect a leader. The lead vehicle drives and other vehicles follow automatically. Our scheme facilitates convoy driving in terms of (i) convoy formation, (ii) convoy leader election, (iii) autonomous driving, (iv) efficient message dissemination and (v) decision coordination within a convoy.

The rest of the paper is organized as follows: In section 2, we present our motivating scenario with a set of requirements. In section 3, we describe our context-based grouping mechanism. Simulated experiments and results are presented in section 4. In section 5, we discuss some related work in comparison to our proposed scheme. We present the conclusion with suggestions for future work in section 6.

2. Motivating scenario and requirements

In this section we describe a motivating scenario from which we extract a set of requirements for efficient context-aware communication in VANETs.

2.1. Scenario

Efficient dissemination of information about a traffic incident to all the on-coming vehicles is hard to achieve [10]. Traditionally in the event of a traffic incident the information about the type, location and time of the incident is sent to the vehicles either over the radio waves or from a central server to an embedded Global Positioning System (GPS) inside each of the vehicles. The problem with such a system is that vehicles are informed too late about the incident, the information itself is usually received several times, and the information is broadcasted to vehicles for which the information is irrelevant. For example, an accident occurs on the E40 highway from Leuven to Brussels, causing a traffic jam. The information about this accident is broadcasted on the radio. The drivers are informed and they try to avoid the traffic jam. However, it takes a certain amount of time from the moment that the accident occurs to the time that the authorities are informed. Thus, there may be quite a large number of vehicles that get blocked on the road due to the late arrival of this information.

By taking into consideration the kind of information vehicles share with other nodes in the network, we can easily identify a number of vehicles acting as groups with similar information interests at a given time, location and direction. For example, on the E40 highway all the vehicles driving in the same direction could be part of a single group based on the common location and direction. Within this large group there may be vehicles that could be interested in information on traffic moving on the highway towards a particular city. These context-based groups reduce the redundant and irrelevant information flow between several vehicles, thus also ensuring on-time information delivery to the vehicles moving towards a traffic incident.

2.2. Requirements for efficient context-aware communication in VANETs

We present a three-layered approach in which we have a middleware layer in between the application layer and the physical network layer. Our context-aware grouping mechanism lies inside the middleware layer. The middleware layer provides the applications with transparent access to relevant context information.

In order to optimize the information dissemination in VANETs using context-based grouping we derive a set of generic requirements from various use-case scenarios.

- *Location and direction-aware delivery of relevant information*: We need to know the exact location of an incident to inform the authorities and to notify only vehicles moving towards the incident.
- *On-time delivery of information*: It is quite critical that the information being disseminated in a large scale network, either between nodes or between groups of nodes, reaches the destination on-time. For example, information about a free parking spot may not be relevant for interested vehicles if the message arrives only 30 mins after being disseminated from the vehicle as it left the parking spot.
- *Optimize communication overhead and delivery efficiency*: Messages should be routed in a network in an efficient way causing least amount of overhead. We should know how much data is being transmitted over the network and how much of it is being used. This quantification will help to properly analyze, improve and compare various information sharing algorithms and communication protocols on the basis of the contextual parameters. In this paper we quantify our optimization mechanism using context-based grouping.

3. Context-aware group-based communication in large-scale vehicular networks

In this paper we propose a context-aware group-based communication system for vehicular networks. We used group-based communication for several reasons:

- *To reduce network traffic*: By forming groups of vehicles and choosing representatives for each group, we can limit the communication traffic in the network of vehicles. Instead of every single vehicle participating in message forwarding, we choose certain specific nodes for each group of vehicles and make them responsible for the communication with the nodes inside their group and with the other groups.
- *To reduce processing overhead*: Without grouping, every single node has to process every message it receives and then, on the basis of its own interests and the interests of its neighbors, it has to decide what to do with each message. With the use of grouping, only the groups representative nodes are required to make these kinds of decisions. This reduces the processing overhead in a large percentage of the nodes.
- *To decrease redundant messages*: Using representative nodes as brokers to take care of the communication between groups and within groups prevents the generation of redundant messages, such as duplicates being forwarded again within the groups. Filtering redundant messages sooner prevents them from being further propagated.
- *To prevent the propagation of irrelevant information*: Representative nodes know about the interests of the nodes inside their group. Thus, upon receiving a message with irrelevant information (information that interests no member of the group), the representative node will not further propagate the message within the group.

In this system, we assume that all the vehicles are equipped with positioning devices such as GPS and also with communication capabilities, such as Dedicated Short Range Communication (DSRC) for vehicular networks. We collect the location data from the positioning devices and we propagate this data using the wireless devices. Using these propagated data we make different groups of vehicles. In order to form the groups, we use two criteria:

- Location of a vehicle ($Location_x, Location_y$): The location of a vehicle is specified by its latitude and longitude, which are provided by the positioning device.
- Direction of a vehicle ($Direction_x, Direction_y$): The direction is calculated on the basis of the difference between the last two data items collected from the positioning device. It is indicated as a vector.

We also make subgroups inside a group of vehicles on the basis of their interests, including such things as traffic jams, accident information, parking information, weather situation, etc. For example, if we have 10 vehicles in a group, 4 of these vehicles may be interested in parking information. For this purpose, then, we make a subgroup of those 4 vehicles and we call it the parking subgroup. Therefore the common criterion for group and subgroup formation is:

$$Group(G) = \{Location, Direction, Interest\} \tag{1}$$

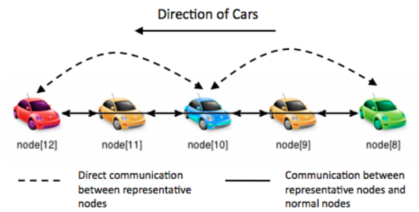
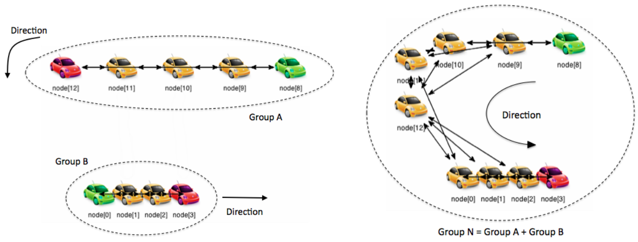


Fig 1: A simple group structure: The red car is a Head Node and is moving ahead of the other cars. The blue car is a Relay Head. The green car is a Tail Node and is moving behind the other cars. The yellow cars are normal cars.



(a) Before Merging

(b) After Merging

Fig 2: A merging scenario. Two groups of cars are being merged after the upper group joins the cars which are moving in a straight road. The red car is a Head Node. The green car is a Tail Node. The yellow cars are normal cars.

3.1. Group formation

Each group in our system consists of up to 4 types of vehicles: (i) *Head Vehicle*: a vehicle which is leading a group of nodes moving in the same direction, (ii) *Tail vehicle*: the last vehicle in group, (iii) *Relay Head*: Relay Heads exist in large groups in which the Head and Tail Vehicles are outside each others wireless communication range. Relay Heads are formed inside a group to enable full transmission coverage of all the nodes in a group and (iv) *Normal Vehicle*: a vehicle which does not have any of the above roles. A simple group structure with different roles is illustrated in Fig 1.

In order to form the groups, nodes periodically send their location and direction information to the other nodes in their vicinity. For this purpose, we use `POSITION_MESSAGE`. Each `POSITION_MESSAGE` contains the sender's location (x, y), direction (dir_x, dir_y) and role (i.e. Head, Tail, Relay Head or Normal node). Each node, upon receiving a `POSITION_MESSAGE` from its neighbor, appends that information to a list which contains the information about the neighbors. We call this list the neighbors list. If an old item of information from same neighbor is already in the list, it will be updated with the new information.

On the other hand, each node periodically checks whether it should change its role. All the vehicles start as Normal Nodes. They change roles on the basis of the following conditions: a vehicle becomes Head if there is no other vehicle which has the same direction and is moving ahead of it, a vehicle becomes Tail if there is no other vehicle which has the same direction and is moving behind it, a vehicle becomes Relay Head if there is no other Head which has the same direction, is moving ahead of it and is closer than the maximum `RELAY_DISTANCE`. All the other vehicles are Normal Nodes.

For direction calculations we compare the direction vector of each pair of vehicles ($vehicle_a$ and $vehicle_b$) and we calculate their difference in degrees. If this value is less than a certain limit `DIRECTION_CONVERGENCE`, we say that these two vehicle have the same direction. Similarly, to decide whether a vehicle is moving in front or behind another vehicle, we compare the location vector for a pair of vehicles (i.e. the vector which goes from $vehicle_b$ to $vehicle_a$) with the direction vector of $vehicle_a$. If the difference between these two vectors is less than `DIRECTION_CONVERGENCE` and the two vehicles are moving in the same direction, then $vehicle_a$ is moving ahead of $vehicle_b$. The following algorithm shows the Head Vehicle calculation logic. Calculating the Tail Vehicle is almost the same. Calculating the Relay Head is similar.

for all neighbors in neighbor list of $vehicle_a$ **do**
    $dir_{diff} = abs(dir_a - dir_{neighbor})$
    if $dir_{diff} \geq 2\pi$ **then**
        $dir_{diff} = 2\pi - dir_{diff}$
    end if
    if $dir_{diff} \leq direction\_convergence$ **then**
        $vehicle_a$ and $vehicle_{neighbor}$ have the same direction
        $posvector = abs(pos_a - pos_{neighbor})$
        $diff = abs(dir_a - posvector)$

if $diff \geq 2\pi$ **then**
$diff = 2\pi - diff$
end if
if $diff \leq direction\_convergence$ **then**
$vehicle_a$ is ahead of $vehicle_{neighbor}$
$vehicle_a$ can become a head, check next neighbors
else
$vehicle_a$ cannot become a head, break from the loop
end if
else
$vehicle_a$ and $vehicle_{neighbor}$ do not have the same direction
check the next neighbor
end if
end for

As vehicles move and change their formation, groups change accordingly. For example, if a faster group of vehicles reaches a slower group which is moving in front of the faster group, the two groups will merge and form a single group. It is also the same case with a group of vehicles that join a highway from another road and merge with another group, as illustrated in Fig 2.

3.2. Inter-group communication

The communication between groups is done through the representatives of the groups, which are Heads, Tails and Relay Heads. These are the only vehicles that can take part in forwarding messages. Although they have different electing algorithms and different characteristics, they do the same job in forwarding messages. Any vehicle belonging to these three types of vehicles can send and receive messages to and from any of these three types of vehicles. These types of vehicles act like gateways for the Normal Nodes inside their groups.

In order to establish an intelligent mechanism in which nodes can share information, to form groups with common interests and to do context-sensitive tasks in a network, we need feedback from all the participating nodes. In order to achieve the objectives mentioned earlier, we introduce a special kind of additional filter mechanism based on relevance backpropagation to be used for inter- and intra-group communication. We describe the relevance backpropagation mechanism later in this section.

3.3. Intra-group communication

Heads, Tails and Relay Heads are also responsible for intra-group communication. Each vehicle inside a group periodically sends its interests to these representative vehicles. In order to save our network resources, we use the `POSITION_MESSAGE` and we piggy-back the interests of a vehicle on the same message. Representative vehicles keep an interest list for their group members and keep them updated with `POSITION_MESSAGE`s that they receive. When a forwarded message is delivered at one of the representative vehicles, the system tries to find a match between the type of the information in the message and the interests in the interest list. If there is a match, the representative vehicle forwards the message to the matched members in the group. If not, the message will just be forwarded to the other representative vehicles to continue the propagation of the message. We keep the interests of a vehicle as the *one* and *zero* values in a binary representation of a number. For example, if we consider the first three places of a binary number to show interest in parking, traffic and accident information, then"`101`" shows interest in parking and accident information and no interest in traffic information. We can find a match using a simple "logical and" operation. By using binary operations, we save memory, network and processing resources. The following algorithm shows the matching procedure:

for all interests in my interest list **do**
if $message_{type} \wedge interest[i] > 0$ **then**
there is an interest match
forward message
end if
end for

3.4. Relevance backpropagation

Our relevance backpropagation algorithm relies on the feedback of neighboring nodes to reduce the number of peers to which the information needs to be forwarded. The information is initially forwarded to the adjacent nodes unless a maximum number of hops or other contextual criteria is reached. Each forwarding node reduces the hop counter, adds its identification and marks the message relevancy tag if the information is relevant for its purpose. The feedback technique is based on context parameters such as position, velocity, direction, time-to-live, interest, etc., which determines whether the data that was received is relevant or not, and whether the information was used. The feedback to the delivering node is initiated when the context information is relevant, irrelevant, unused or a duplicate. As the context information can be provided by the application itself, the routing of the information is adapted accordingly. So the network re-calibrates itself if a node joins or leaves the group. The goal is to efficiently route and filter the relevant information as close to the source as possible. Relevance backpropagation also ensures that the messages do not loop around in the network. More details on the basic relevance backpropagation algorithm can be found in [8].

4. Experimental results and discussion

Developing a context-based grouping mechanism for real vehicles is very costly in terms both of time and money. Simulations, on the other hand, have the benefit of creating an ideal situation where we can (i) produce results faster, (ii) compare different algorithms under the same conditions and (iii) reproduce results. Nonetheless, cross validation of the simulated results in a realistic environment is important.

In this section, we first describe the simulation environment and the experimental setup, and then we show and analyze the results of our experiments. We end the section with a discussion of the results.

4.1. Simulated experimentation

We set up a simulation test bed to evaluate our optimizing information dissemination using context-based grouping in a large scale vehicular network. We then performed four types of simulated experiments, (i) urban environment with context-based grouping, (ii) urban environment without context-based grouping, (iii) highway environment with context-based grouping and (iv) highway environment without context-based grouping. In an urban environment setting we have a larger number of intersections. The traffic is slower and moves more or less at a constant speed. The vehicles change directions more often, and therefore the groups are more dynamic than in a highway setting. On the other hand, in a highway environment setting, the vehicles move in different lanes of the highway, at variable speeds and frequently overtaking one another. On the other hand, the vehicles on a highway are more likely to stay with the same group. Therefore we expect to have less dynamic grouping behavior in the highway setting.

The type of wireless network used in our simulated experiments is Dedicated Short Range Communication (DSRC). It is commonly used for vehicle-to-vehicle and vehicle-to-infrastructure communication. It operates over a 5.9 GHz band, with a transmission range from 10m - 1000m and a transmission rate of 25 Mbps - 0.25 Mbps. We use 200 vehicles in our simulated experiments, which move within a geographical area of 20km $\times$ 10km in a period of five minutes. However, due to the limitations of the network simulator we were not able to run experiments with much larger datasets. We performed our simulations using OMNeT++ and MiXiM.

4.2. Results and discussion[1]

There are several types of messages in our simulated experimentation, such as (i) sent (M_s), (ii) unique received (M_{ur}), (iii) unique sent (M_{us}), (iv) forwarded (M_f), (v) duplicate (M_d) and (vi) dropped (M_{drop}). We measured the following parameters during our simulated experimentation and present them as follows:

[1] We performed 3 iterations of each experiment with different random number generator seeds in order to perform statistical analysis. The results are shown as averages of the iterations with 95% confidence interval.

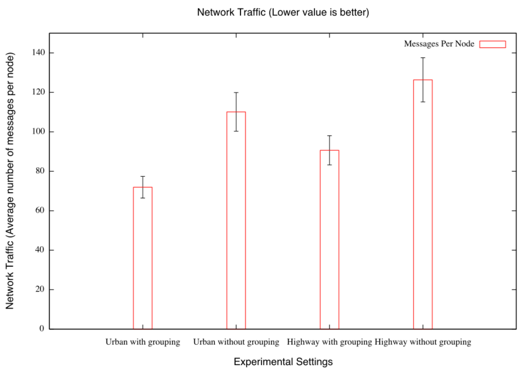


Fig 3: Network traffic utilization in VANETs under different experimental settings

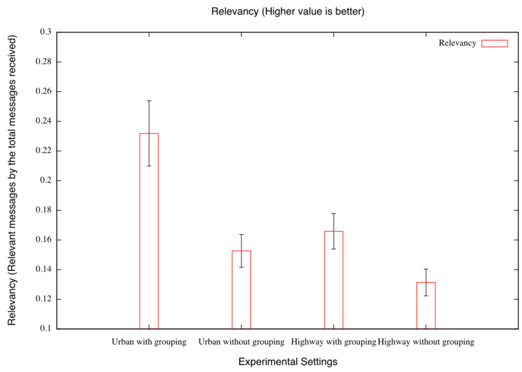


Fig 4: Relevancy of information received in VANETs under different experimental settings

- Network Traffic (NT): $NT = \Sigma_n(M_s + M_f)$

  In Fig 3 there is a significant difference of 36% reduction for the urban setup and 28% reduction for the highway setup in network traffic utilization for our context-based grouping mechanism as compared to the group-less approach. In a large scale vehicular network, a lower network traffic is desirable and always considered to be better.

  The results obtained for the network traffic utilization have a close relationship with our simulated experimental setups discussed earlier. In Fig 3 we can see that there is a higher average number of messages per nodes for the highway setting as compared to the urban setting with and without grouping. This behavior occurs due to the different road layouts in the real world. We know that vehicles on a highway tend to follow each other in a sequential way. Similarly, vehicles in an urban setting remain in different small clusters which are not inter-connected with each other. We can see that in the former case, for the same number of vehicles, we have a higher probability of connectivity between vehicles resulting in higher network traffic utilization in contrast to the latter setting. Our context-based grouping mechanism reduces the network traffic utilization by ensuring that only the relevant information is provided to the interesting nodes in VANETs.

- Relevancy (R): $R = \Sigma_n((M_{ur} + M_d) - M_{drop})/\Sigma_n(M_{ur} + M_d)$

  If a node in a network receives a message from another node and the message is relevant either for itself or for one of its neighboring nodes, then this message is considered to be relevant. In Fig 4, there is a significant difference of about 32% for the urban setup and 24% for the highway setup for our context-based grouping mechanism as compared to the group-less approach. This illustrates the fact that nodes get more relevant information (i.e. the nodes receive less information they are not interested in) and a higher relevancy ratio is considered to be better.

  We can see that the relevancy ratio is slightly higher for the urban setup than the highway setup with grouping. This is first of all because in the highway setup, vehicles tend to resend same unique messages as compared to the urban setup which results in a network traffic usage (as shown in Fig 3). The second reason is that in the highway setup, vehicles also send more duplicate messages as compared to the urban setup which also results in higher amount of information being filtered out (as shown later in Fig 5). These two behaviors on a highway are due to the long-term sequential connectivity of the vehicles which is opposite in an urban setup.

- Filtering (F): $F = (1 - (M_f/\Sigma_n(M_{ur} + M_d)))$

  This parameter is measured at each node where the node receives a number of messages but only forwards those messages to other nodes that are relevant for them for a given time period. In Fig 5, the filtering ratio for our context-based grouping mechanism is almost the same as in the group-less experimental settings. This behavior is due to our relevance backpropagation algorithm, which ensures that the irrelevant information is filtered out. The information is filtered at the representative nodes in our context-based grouping mechanism

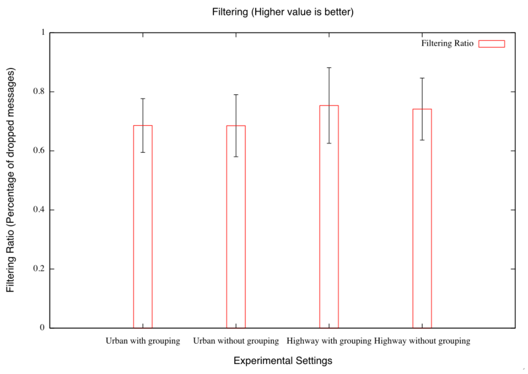


Fig 5: Information filtering rate in VANETs under different experimental settings

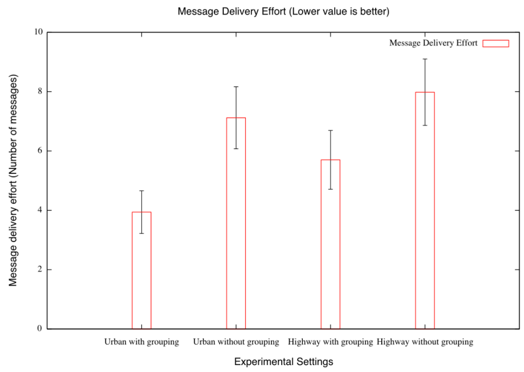


Fig 6: Message Delivery Effort in VANETs under different experimental settings

and at general nodes in the case of group-less communication. In general, the higher the filtering ratio the better it is in VANETs.

We can deduce from the results obtained that by using our context-based grouping mechanism we can filter-out more irrelevant and redundant information from the network in a highway set as compared to the urban setup. This is because in our experiments we observed better connectivity between vehicles and a higher network traffic utilization.

- Delivery Effort (DE): $DE = \Sigma n(M_{ur})/\Sigma n(M_{ur} + M_{drop})$

  The Message Delivery Effort shows for a single relevant message how many copies are produced at each intermediate processing step before it can reach its destination. Generally, a lower delivery effort is considered to be better in VANETs. According to Fig 6, about 50% less delivery effort for the urban setup and about 30% less delivery effort for the highway setup is required for a message to reach its destination for our context-based grouping mechanism as compared to the group-less approach.

  We can see that the message delivery effort is higher for the highway setup as compared to the urban setup with and without our context-based grouping mechanism. This is again due to the sequential connectivity of the vehicles on a highway. The vehicles tend to follow a pattern and usually drive behind each other. So we observed in our experiments that a message sent from a certain node in the network might have to pass through several intermediate nodes before it can reach its destination. On the contrary, we observed that, for the same number of messages, in an urban setup most of the messages could be delivered in one or two hops resulting in a lower message delivery effort.

- Message Drop Ratio (DR): $DR = \Sigma n(M_{drop})/Num_{nodes}$

  Message drop ratio is the average number of dropped messages per node. Fig 7 shows that the number of dropped messages decreases when our grouping mechanism is used. The reason for this is that our mechanism reduces the overall network traffic and thus there are less irrelevant/redundant messages propagated in the network. For example, the vehicles moving in the one direction on a highway can send messages to the vehicles moving in the other direction on the same highway, but these messages are usually irrelevant (and thus not further propagated) due to the direction in which the vehicles are moving.

  The reduction of these irrelevant/redundant messages also reduces the processing effort required by each node for filtering.

We can conclude from the results presented earlier in this section that our context-based grouping mechanism *reduces the network traffic usage*, *reduces the propagation of irrelevant and redundant information* and *reduces the processing overhead* at each node by providing them with less inconsistent information.

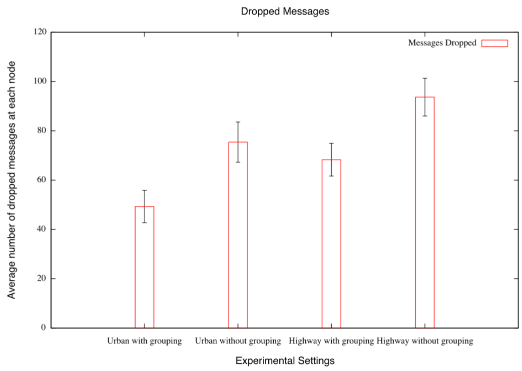


Fig 7: Average number of dropped messages at each node in VANETs under different experimental settings

5. Related work

Qin et al. [11] address the problem of road traffic safety by integrating the vehicles and road infrastructure with the inexpensive wireless sensor networks (WSNs). The sensors along the roadside detect the road conditions, and buffer and transmit this information to the clusters of vehicles. Each cluster of vehicles has a head node, which receives all the information from the roadside sensors and then broadcasts this information to other vehicles inside the cluster using a TDMA-based approach. In our approach, we eliminate the irrelevant and redundant communication between vehicles by using context-based grouping. In each group we have Head, Relay Head and Tail nodes, which are responsible for the communication. In our mechanism the groups are formed on the basis of certain common criteria such as location, direction and information interests. These criteria are used by our system later on for the filtering and routing of information.

The optimization of context information dissemination is a vital characteristic for every context-aware application in use. In the literature, centralized solutions in which a server collects and manages information are numerous [12]. For example, Henricksen et al. [13] and Paganelli et al. [14] propose centralized entities that manage the context information and handle the client requests for it. These centralized approaches are prone to scalability and single point of failure. In our approach we optimize the information flow between the highly dynamic and mobile nodes in a large scale network using context-based grouping incorporated with our relevance backpropagation mechanism in order to achieve information delivery only to the relevant nodes and without relying on any centralized architecture.

Cutting et al. [15] propose implicit group definition based on tags used by users to identify interesting content. Peers interested in the same content tags are considered to belong to the same implicit group. Messages are then addressed to the tags forming the groups. Similarly Khambatti et al. [16] propose a grouping technique based on the notion of community. Communities are groups formed based on users (or peers) common interests, declared as peer attributes. Our approach is also stimulated by the dynamic group definition proposals presented earlier by these researchers. We improve this scheme by dividing up the groups on the basis of interests and locations. The information flow is also intelligent and context-aware, taking into account the primary concerns of privacy by using our relevance backpropagation algorithm.

Nadeem et al. [17] present a formal model of data dissemination in VANETs. They measure how the performance of data dissemination is affected by bi-directional lane mobility. Three models of data dissemination are explained and simple broadcasting technique is found to be sufficiently enough in their simulated experiments. In our approach we form groups and disseminate the information between the groups using the relevance backpropagation algorithm.

6. Conclusion and future work

Context-aware communication is considered to be vital for more intelligent inter-vehicular communication. Contextual properties such as location, direction, speed, time and information interest are taken into account. However, traditional network addressing schemes are not well suited because they do not take this information into account for group-based communication in large scale vehicular networks. The classical network paradigms of multicasting and broadcasting to define groups cause too much overhead. First, there is no way to optimize network traffic based on the contextual characteristics of the nodes. Second, they do not take into account the mobility patterns of the vehicles and the road layouts. We propose a context-based grouping mechanism in which only relevant information is shared among the vehicles in a group. We evaluate our approach by formulating groups based on common spatial-temporal characteristics and shared interests. The simulated experiments show that by inducing our context-based grouping mechanism we can significantly reduce the irrelevant/redundant information flow, the message delivery effort and the overall network traffic usage, as discussed in Section 4.

We plan to further investigate the network and context properties in order to achieve a more realistic simulation of the communication protocols used earlier in our experiments. We also plan to look into implicit grouping in larger networks by analyzing the network traffic and automatically inferring the common interests of the nodes without relying on an explicit definition of interests. And finally, we plan to investigate how effective collaboration with context-based grouping can be used in various traffic shaping scenarios.

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